(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 091 008 B1

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
29.09.2004 Bulletin 2004/40

(51) Int Cl.[7]: C22B 9/02, B22D 27/02

(21) Application number: 00109245.1

(22) Date of filing: 28.04.2000

(54) **Apparatus for generating compression waves in conductive liquid**

Vorrichtung zum Erregen von Kompressionswellen in einer elektrisch leitenden Flüssigkeit

Dispositif pour générer des ondes de compression dans un liquide électro-conducteur

(84) Designated Contracting States:
DE FR

(30) Priority: 05.10.1999 JP 28425699

(43) Date of publication of application:
11.04.2001 Bulletin 2001/15

(60) Divisional application:
04003291.4 / 1 435 396

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## Description

### BACKGROUND OF THE INVENTION

Field of Invention:

**[0001]** The present invention relates to an apparatus as given in the preamble of claim 1, for generating compression waves in a conductive liquid, such as a molten metal.

Description of the Related Art:

**[0002]** There have been poured intensive efforts in developing a technique that generates compression waves in a molten metal contained in a container and aims at an improvement of the tissues after the solidification of the molten metal and an enhancement of refining capabilities. However, it is considered difficult, at the present stage, to efficiently achieve a higher strength of the compression waves, and satisfactory results have not yet been accomplished.

**[0003]** Accordingly, there is a need to provide an apparatus for generating compression waves in a conductive liquid contained in a vessel, which improves an ac electromagnetic force applying means that generates the compression waves directly in the conductive liquid contained in the vessel, and thereby enhances the strength of the compression waves sufficiently.

**[0004]** An apparatus as given in the preamble of claim 1 is described in AMANO S. ET AL: 'Non-contact generation of compression waves in a liquid metal by imposing a high frequency magnetic field', ISJI INTERNATIONAL, JAPAN, 1997, vo. 37, no. 10, pages 962 to 966.

**[0005]** In this paper, an experimental apparatus for generation of compression waves in a liquid metal is described and shown. The apparatus contained a liquid gallium poured up to 56 mm depth in an acrylic vessel with a cross section of $50 \times 50$ mm$^2$. An alternating magnetic field of 2.2 kHz was imposed by the gallium by a 10-turns coil placed under the vessel.

Thus, AMANO S. ET AL disclose an apparatus for generating compression waves in a conductive liquid, which comprises a vessel containing a conductive liquid and an ac electromagnetic force applying means that generates the compression waves in the conductive liquid contained in the vessel. The ac frequency f = 2.2 kHz of the ac electromagnetic force applying means lies within a range given by the following [expression 1]:

[expression 1]

$$\frac{2}{L^2\pi\mu\sigma} \leqq f \leqq \frac{c^2\mu\sigma}{2\pi}$$

**[0006]** Here, f: frequency (a major frequency when a wave-form of an electromagnetic force is developed by the Fourier transform, in case of the wave-form being a non-sine wave)

L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)
μ: permeability of the conductive liquid
σ: electric conductivity of the conductive liquid
c: propagation velocity of the compression waves in the conductive liquid.

**[0007]** In the DE-C-972 054 as published on 14 May 1959, a further apparatus for generation of compression waves in a molten metal is described. The known apparatus has two equiaxed coils, one of them being traversed by a high frequency current, the other coil is traversed by a direct current. Such a dc magnetic field and an ac magnetic field are produced. As example, the high frequency coil of an induction furnace is used at least for one of the coils.

**[0008]** Starting from the closest prior art as given in the scientific paper of AMANO S: ET AL, the problem of the invention is to improve an apparatus as given in the preamble of claim 1 in such a way that the generation of stronger compression waves is possible.

**[0009]** This problem is solved by an apparatus having the features of the enclosed claim 1.

**[0010]** Advantageous embodiments are given in the dependent claims.

**[0011]** The invention discloses an apparatus for generating compression waves in a conductive liquid, which comprises a vessel containing a conductive liquid and an ac electromagnetic force applying means that generates the compression waves in the conductive liquid contained in the vessel, in which an ac frequency f of the ac electromagnetic force applying means is set within a range given by the following [expression 1]:

[expression 1]

$$\frac{2}{L^2\pi\mu\sigma} \leqq f \leqq \frac{c^2\mu\sigma}{2\pi}$$

Here,

f: frequency (a major frequency when a wave-form of an electromagnetic force is developed by the Fourier transform, in case of the wave-form being a non-sine wave)
L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)
μ: permeability of the conductive liquid
σ: electric conductivity of the conductive liquid
c: propagation velocity of the compression waves inthe conductive liquid.

[0012] According to one aspect of the invention, the ac electromagnetic force applying means in the apparatus for generating compression waves in a conductive liquid is an ac magnetic field generating electromagnetic coil, which is provided around the circumference of the vessel and a dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel. The dc magnetic field generating electromagnetic coil is a superconducting magnet, and the vessel and the ac magnetic field generating electromagnetic coil are inserted in the bore of the superconducting magnet.

[0013] According to one embodiment of the invention, the ac electromagnetic force applying means comprises a pair of electrodes that are installed at positions on the circumferential wall of the vessel facing to each other so as to energize the conductive liquid, and an ac power supply connected to the electrodes.

[0014] According to a further embodiment of the invention, the dc magnetic field generating electromagnetic coil is provided around the circumference of the vessel provided with the electrodes.

[0015] Preferably, the vessel with a pair of the electrodes is inserted in the bore of the superconducting magnet.

[0016] According to another embodiment of the invention, the vessel of an apparatus for generating compression waves in a conductive liquid is formed of ceramics and provided with a metal reinforcing material on the circumference thereof, and an ac magnetic field generating electromagnetic coil as the ac electromagnetic force applying means is provided overlying the vessels.

[0017] According to the present invention relating to the aforementioned apparatus for generating compression waves in a conductive liquid, since the ac frequency of the ac electromagnetic force applying means that generates the compression waves in a conductive liquid contained in a vessel is set within an appropriate range by the reason described later, the compression waves can be generated with a certain strength. Thereby, degassing of the conductive liquid and micro structuring of the tissues are effectively processed, and material improvement after the solidification of the conductive liquid will be brought about efficiently.

[0018] And, when the ac magnetic field generating electromagnetic coil as the ac electromagnetic force applying means is installed around the circumference of the vessel, the compression waves will be generated in the conductive liquid with a simplified construction and a low cost.

[0019] And, when, in addition to the ac magnetic field generating electromagnetic coil, a dc magnetic field generating electromagnetic coil is further installed around the circumference of the vessel, the superimposition of both the electromagnetic coils effects a stronger generation of the compression waves in the conductive liquid contained in the vessel. Thereby, enhancement of the refining capabilities after the solidification of the conductive liquid and improvement of the tissues will sufficiently be accomplished.

[0020] Further, when, while the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, the foregoing vessel and the ac magnetic field generating electromagnetic coil are inserted in the bore of the superconducting magnet, the superimposition of both the dc magnetic field generating electromagnetic coil as the superconducting magnet and the ac magnetic field generating electromagnetic coil effects a still stronger generation of the compression waves in the conductive liquid contained in the vessel, and material improvement after the solidification of the conductive liquid is achieved still more efficiently.

[0021] Further, when the ac electromagnetic force applying means is made up with a pair of electrodes that are installed at positions on a circumferential wall of the vessel facing to each other so as to energize the conductive liquid in the vessel, and the ac power supply connected to the electrodes, and furthermore the dc magnetic field generating electromagnetic coil is installed around the circumference of the vessel, the ac magnetic field generating electromagnetic coil is not required. Accordingly, the total construction of the apparatus is simplified remarkably, and in addition, the compression waves are generated efficiently in the conductive liquid contained in the vessel so as to contribute to material improvement after the solidification of the liquid.

[0022] And, also in this case, when the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, in the bore of which is inserted the vessel with the electrodes, the effect of a strong electromagnetic force by the dc magnetic field generating electromagnetic coil as the superconducting magnet is superimposed on the effect by the ac electromagnetic force applying means by a pair of the electrodes, which generates the compression waves still more effectively in the conductive liquid contained in the vessel, thereby achieving material improvement after the solidification of the liquid.

[0023] Further, while the vessel maintains a sufficient strength reinforced by the metal reinforcing material, when it is provided with the ac magnetic field generating electromagnetic coil to overlie the vessel, the apparatus is able to generate intensified compression waves in the conductive liquid contained in the vessel without being influenced by the metal reinforcing material. Thus, degassing of the conductive liquid and micro structuring of the tissues are effectively processed, whereby material improvement after the solidification of the conductive liquid will be accomplished.

[0024] Further, when the superimposition effect by the ac magnetic field generating electromagnetic coil provided overlying the vessel and the dc magnetic field generating electromagnetic coil provided around the circumference of the vessel is configured to generate intensified compression waves in the conductive liquid contained in the vessel, the material improvement after

the solidification of the conductive liquid will be achieved more appropriately.

**[0025]** And, when the dc magnetic field generating electromagnetic coil provided around the circumference of the vessel is made up with a superconducting coil in pursuit for the superimposition effect by association with the ac magnetic field generating electromagnetic coil provided overlying the vessel, a still stronger generation of the compression waves in the conductive liquid contained in the vessel will be brought about, and a sufficient material improvement after the solidification of the liquid will be accomplished.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0026]**

Fig. 1 is a perspective view to typically illustrate an apparatus for generating compression waves in a conductive liquid;
Fig. 2 is an explanatory drawing to typically illustrate a second apparatus for generating compression waves in a conductive liquid;
Fig. 3 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as an embodiment of the invention;
Fig. 4 is an explanatory drawing to typically illustrate a further apparatus for generating compression waves in a conductive liquid;
Fig. 5 is an explanatory drawing to typically illustrate a further apparatus for generating compression waves in a conductive liquid;
Fig. 6 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as an embodiment of the invention;
Fig. 7 is an explanatory drawing to typically illustrate a further apparatus for generating compression waves in a conductive liquid;
Fig. 8 is an explanatory drawing to typically illustrate a further apparatus for generating compression waves in a conductive liquid; and
Fig. 9 is an explanatory drawing to typically illustrate an apparatus for generating compression waves in a conductive liquid as an embodiment of the invention.

## DETAILED DESCRIPTION

**[0027]** As shown in Fig. 1, an apparatus for generating compression waves comprises a vessel 2 containing a conductive liquid 1 (for example, molten metals, plastics, high-temperature liquid semiconductors, or ceramics, etc.), and an ac magnetic field generating electromagnetic coil 3 installed around the circumference of the vessel 2 as an ac electromagnetic force applying means, whereby a vertical ac magnetic field $B_{AC}$ can be generated.

**[0028]** And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, a frequency f of an ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by a frequency controller 5 within the range given by the [expression 1].

[expression 1]

$$\frac{2}{L^2\pi\mu\sigma} \leqq f \leqq \frac{c^2\mu\sigma}{2\pi}$$

Here,

f: frequency (a major frequency when a wave-form of an electromagnetic force is developed by the Fourier transform, in case of the wave-form being a non-sine wave)
L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)
μ: permeability of the conductive liquid
σ: electric conductivity of the conductive liquid
c: propagation velocity of the compression waves in the conductive liquid

**[0029]** The reason why the frequency f is set within the foregoing range is as follows. That is, the range where an electromagnetic force acts on a conductive liquid practically covers a depth from the surface, which is known as the depth of electromagnetic penetration. Provided that this depth of electromagnetic penetration is greater than the characteristic length L of the system, the electromagnetic force will not be generated efficiently. Therefore, to efficiently generate the compression waves, it is necessary to make the depth of electromagnetic penetration smaller than the characteristic length L of the system. This condition is given by the [expression 2].

[expression 2]

$$\frac{2}{L^2\pi\mu\sigma} \leqq f$$

**[0030]** On the other hand, a wavelength in a higher frequency region can be smaller than the depth of electromagnetic penetration. Under this condition, the compression waves cannot efficiently be generated. Therefore, to efficiently generate the compression waves, it is necessary to make the depth of electromagnetic penetration greater than the wavelength of the compression waves. This is given by the [expression 3].

[expression 3]

$$f \leqq \frac{c^2 \mu \sigma}{2\pi}$$

[0031] In the foregoing apparatus for generating compression waves in a conductive liquid, the ac frequency f of the ac electromagnetic force applying means that generates the compression waves in the conductive liquid 1 contained in the vessel 2 is set within an appropriate range by the aforementioned reason, and the compression waves can be generated with a sufficient strength accordingly. Thereby, degassing of the conductive liquid and micro structuring of the tissues are effectively processed, and material improvement after the solidification of the liquid will be brought about efficiently.

[0032] And, since the ac electromagnetic force applying means is installed around the circumference of the vessel 2 as the ac magnetic field generating electromagnetic coil 3, the generation of the compression waves in the conductive liquid contained in the vessel will be carried out with a simplified construction and a low cost.

[0033] Next, a second apparatus for generating compression waves in a conductive liquid will be described. As shown in Fig. 2, also this apparatus comprises the vessel 2 containing the conductive liquid 1 (for example, molten metals or plastics, etc.), and the ac magnetic field generating electromagnetic coil 3 installed around the circumference of the vessel 2 as the ac electromagnetic force applying means, whereby the ac magnetic field $B_{AC}$ can be generated vertically.

[0034] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0035] In this second apparatus, a dc magnetic field generating electromagnetic coil 6 is further installed so as to surround the circumference of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby a vertical dc magnetic field $B_{DC}$ can be generated which passes through the conductive liquid 1.

[0036] In the second apparatus, the superimposition of the ac magnetic field generating electromagnetic coil 3 and the dc magnetic field generating electromagnetic coil 6 effects a still stronger generation of the compression waves in the conductive liquid 1 contained in the vessel 2. Thereby, improvement of the tissues after the solidification of the liquid and enhancement of the refining capabilities will sufficiently be accomplished.

[0037] Next, the apparatus for generating compression waves in a conductive liquid as a first embodiment of the invention will be described. As shown in Fig. 3, also in this embodiment, the apparatus comprises the vessel 2 containing the conductive liquid 1 (for example, molten metals or plastics, etc.), and the ac magnetic field generating electromagnetic coil 3 installed around the circumference of the vessel 2 as the ac electromagnetic force applying means, whereby the ac magnetic field $B_{AC}$ can be generated vertically.

[0038] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0039] And, the dc magnetic field generating electromagnetic coil 6 is further installed so as to surround the circumference of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby the vertical dc magnetic field $B_{DC}$ can be generated which passes through the conductive liquid 1. However, in this embodiment, the dc magnetic field generating electromagnetic coil 6 is configured to function as a superconducting magnet by a cooling means 6a being a double cylindrical wall-formed container that contains a very low temperature liquid such as a liquefied helium to soak the electromagnetic coil 6. And, the vessel 2 containing the conductive liquid 1 and the ac magnetic field generating electromagnetic coil 3 are inserted in the bore of this superconducting magnet.

[0040] Thereby, the superimposition effect by the ac magnetic field generating electromagnetic coil 3 and the superconducting magnet 6, 6a generates more intensified compression waves in the conductive liquid 1, for example a molten iron, thereby leading to improvement of the material after the solidification of the liquid still more efficiently.

[0041] Next, a further apparatus for generating compression waves in a conductive liquid will be described. As shown in Fig. 4, the apparatus comprises the vessel 2 containing the conductive liquid 1 (for example, molten metals or plastics, etc.), and a pair of electrodes 7, 7 mounted on the circumferential wall of the vessel 2 as the ac electromagnetic force applying means, whereby an alternate current $J_{AC}$ can be flown through the conductive liquid 1.

[0042] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 connected to the electrodes 7, 7 is set by the frequency controller 5 within the range given by the [expression 1].

[0043] Since this apparatus for generating compression waves in a conductive liquid does not require the ac magnetic field generating electromagnetic coil, the total construction of the apparatus will be simplified remarkably. And in addition, the compression waves can be generated efficiently in the conductive liquid 1 contained in the vessel 2, by setting the frequency f of the applied alternate current within the range given by the [expression 1], based on the aforementioned reason; thus contributing to improvement of the material after solidification of the liquid 1.

[0044] In this apparatus, when the conductive liquid 1

is a high-temperature molten metal, the material of the electrodes 7 is required to be resistant to a high temperature as well as being conductive, and the electrodes 7 are made up with, for example, $ZrB_2$ made of boron and zirconium.

[0045] As shown in Fig. 5, a further apparatus for generating compression waves in a conductive liquid comprises, basically in the same manner as in the apparatus described before, the vessel 2 containing the conductive liquid 1, and a pair of the electrodes 7, 7 mounted on the circumferential wall of the vessel 2 as the ac electromagnetic force applying means, whereby the alternate current $J_{AC}$ can be flown through the conductive liquid 1.

[0046] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 connected to the electrodes 7, 7 is set by the frequency controller 5 within the range given by the [expression 1].

[0047] In this apparatus of Fig. 5, the dc magnetic field generating electromagnetic coil 6 is further installed so as to surround the circumference of the vessel 2, whereby the vertical dc magnetic field $B_{DC}$ can be generated which passes through the conductive liquid 1.

[0048] Thus, in this apparatus, the superimposition of the alternate current $J_{AC}$ flowing through the conductive liquid 1 and the vertical dc magnetic field $B_{DC}$ effects a still stronger generation of the compression waves in the conductive liquid 1 contained in the vessel 2. Thereby, improvement of the tissues after the solidification of the conductive liquid 1 and enhancement of the refining capabilities will sufficiently be accomplished.

[0049] Further, in the second embodiment of the invention shown in Fig. 6, compared with the apparatus in Fig. 5, the dc magnetic field generating electromagnetic coil 6 is configured to function as a superconducting magnet by the cooling means 6a being a double cylindrical wall-formed container that contains a very low temperature liquid such as a liquefied helium. And, the vessel 2 containing the conductive liquid 1 and provided with the eletrodes 7 is inserted in the bore of this superconducting magnet.

[0050] Thereby, the synergistic effect by the alternate current $J_{AC}$ applied to the conductive liquid 1 and the dc magnetic field $B_{DC}$ generated by the superconducting magnet 6, 6a generates more intensified compression waves in the conductive liquid 1, such as a molten iron, thereby achieving improvement of the material after the solidification of the conductive liquid 1 still more efficiently.

[0051] Next, a further apparatus for generating compression waves in a conductive liquid will be described. As shown in Fig. 7, the vessel 2 containing the conductive liquid 1 is formed of ceramics as magnesia (MgO), and a metal reinforcing material 8 (reinforcing metal plate in this embodiment) is applied to the circumference of the vessel 2.

[0052] Further, the ac magnetic field generating electromagnetic coil 3 as the ac electromagnetic force applying means is disposed overlying the vessel 2, so as to generate the vertical ac magnetic field $B_{AC}$ efficiently without being influenced by the metal reinforcing material 8.

[0053] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0054] This apparatus for generating compression waves in a conductive liquid, while the ceramic vessel 2 maintains a sufficient strength given by the metal reinforcing material 8, is able to generate intensified compression waves in the conductive liquid 1 without being influenced by the metal reinforcing material 8 by the ac magnetic field generating electromagnetic coil 3 disposed to overlie the vessel 2. Thus, material improvement after the solidification of the conductive liquid 1 will be accomplished by degassing of the conductive liquid 1 and micro structuring of the tissues.

[0055] Further, in addition to the magnesia having the melting point of 2800°C, the vessel 2 can employ as a material alumina ($Al_2O_3$, melting point 2080°C), silica ($SiO_2$, melting point 1710°C), or the like. For example, it is possible to contain a molten silica as a conductive liquid in a vessel made of a magnesia and apply a treatment to the liquid by means of the compression waves accordingly.

[0056] Next, a still further apparatus for generating compression waves in a conductive liquid will be described. As shown in Fig. 8, the apparatus of this embodiment comprises, in the same manner as in the apparatus described just before, the ceramic vessel 2 with the metal reinforcing material 8, which contains the conductive liquid 1, and the ac magnetic field generating electromagnetic coil 3 overlying the vessel 2 as the ac electromagnetic force applying means, whereby the vertical ac magnetic field $B_{AC}$ can be generated.

[0057] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0058] In this apparatus, the dc magnetic field generating electromagnetic coil 6 is further installed so as to surround a part or the whole of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby the vertical dc magnetic field $B_{DC}$ can be generated which passes inside the conductive liquid 1.

[0059] In this apparatus shown in Fig.8, the superimposition of the ac magnetic field generating electromagnetic coil 3 and the dc magnetic field generating electromagnetic coil 6 effects a still stronger generation of the compression waves in the conductive liquid 1 contained in the vessel 2. Thereby, improvement of the tis-

sues after the solidification of the conductive liquid 1 and enhancement of the refining capabilities will sufficiently be accomplished.

[0060] Further, in the same manner as the apparatus of Fig. 7, the strength of the ceramic vessel 2 for containing a high temperature conductive liquid 1 can be increased sufficiently by the metal reinforcing material 8, and since the ac magnetic field generating electromagnetic coil 3 is disposed overlying the vessel 2, the electromagnetic effect of the coil 3 cannot be influenced by the metal reinforcing material 8.

[0061] Next, the apparatus for generating compression waves in a conductive liquid as the third embodiment of the invention will be described. As shown in Fig. 9, the apparatus of this embodiment also comprises the ceramic vessel 2 with the metal reinforcing material 8, which contains the conductive liquid 1 (molten metals or plastics, etc.), and the ac magnetic field generating electromagnetic coil 3 overlying the vessel 2 as the ac electromagnetic force applying means, whereby the vertical ac magnetic field $B_{AC}$ can be generated.

[0062] And, in order to efficiently generate the compression waves in the conductive liquid 1 contained in the vessel 2, the frequency f of the ac power supply 4 for the ac magnetic field generating electromagnetic coil 3 is set by the frequency controller 5 within the range given by the [expression 1].

[0063] Further, the dc magnetic field generating electromagnetic coil 6 is installed so as to surround the circumference of the vessel 2 and the ac magnetic field generating electromagnetic coil 3, whereby the vertical dc magnetic field $B_{DC}$ can be generated which passes inside the conductive liquid 1; however in the third embodiment, the dc magnetic field generating electromagnetic coil 6 is configured to function as a superconducting magnet by the cooling means 6a being a double cylindrical wall-formed container that contains a very low temperature liquid such as a liquefied helium to soak the electromagnetic coil 6. And, the vessel 2 containing the conductive liquid 1 and the ac magnetic field generating electromagnetic coil 3 are inserted in the bore of this superconducting magnet.

[0064] Thereby, the superimposition effect by the ac magnetic field generating electromagnetic coil 3 and the superconducting magnet 6, 6a generates more intensified compression waves in the conductive liquid 1, for example a molten iron, thereby leading to improvement of the material after the solidification of the conductive liquid 1 still more efficiently.

[0065] As the invention has been described in detail, the apparatus for generating compression waves in a conductive liquid according to the invention will achieve the following effects.

(1) Since the ac frequency of the ac electromagnetic force applying means that generates the compression waves in a conductive liquid contained in a vessel is set within an appropriate range, the compression waves can be generated with a sufficient strength, and thereby, degassing of the conductive liquid and micro structuring of the tissues are effected, and material improvement after the solidification of the conductive liquid is carried out efficiently.

(2) When the ac magnetic field generating electromagnetic coil as the ac electromagnetic force applying means is installed around the circumference of the vessel, the compression waves are generated in the conductive liquid contained in the vessel with a simplified construction and a low cost.

(3) When, in addition to the ac magnetic field generating electromagnetic coil, a dc magnetic field generating electromagnetic coil is further installed around the circumference of the vessel, the superimposition of both the electromagnetic coils effects a stronger generation of the compression waves in the conductive liquid contained in the vessel, and thereby, enhancement of the refining capabilities of the conductive liquid and improvement of the tissues after the solidification of the liquid is sufficiently accomplished.

(4) When the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, and the vessel and the ac magnetic field generating electromagnetic coil are inserted in the bore of the superconducting magnet, the superimposition of both the dc magnetic field generating electromagnetic coil as the superconducting magnet and the ac magnetic field generating electromagnetic coil effects a still stronger generation of the compression waves in the conductive liquid contained in the vessel, and still more efficient improvement of the material after the solidification of the conductive liquid is achieved.

(5) When the ac electromagnetic force applying means is made up with a pair of electrodes that are installed at positions on a circumferential wall of the vessel facing to each other so as to energize the conductive liquid in the vessel and the ac power supply connected to the electrodes, and furthermore the dc magnetic field generating electromagnetic coil is installed around the circumference of the vessel, the ac magnetic field generating electromagnetic coil is not required; and accordingly, the total construction of the apparatus is simplified remarkably, and in addition, the compression waves is generated efficiently in the conductive liquid contained in the vessel so as to contribute to material improvement after the solidification of the liquid.

(6) Also in case of (5), when the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, in the bore of which is inserted the vessel with the electrodes, the effect of a strong electromagnetic force by the dc magnetic field generating electromagnetic coil as the superconducting magnet is superimposed on the effect by the ac electromagnetic force applying mean by

a pair of the electrodes, which generates the compression waves still more effectively in the conductive liquid contained in the vessel, and thereby material improvement after the solidification of the liquid is achieved.

(7) In case that the vessel is formed of ceramics resistant to a high temperature and reinforced by a metal reinforcing material on the circumference of the vessel, when the ac magnetic field generating electromagnetic coil is provided to overlie the vessel so that the electromagnetic effect of the coil is designed not to be influenced by the metal reinforcing material, it is possible to satisfy both the vessel maintaining a sufficient strength and a strong generation of the compression waves in the vessel.

(8) In case of (7), when an electromagnetic coil generating a strong dc magnetic field is provided around the circumference of the vessel, the superimposition effect by association with the ac magnetic field generating electromagnetic coil intensifies generation of the compression waves in the conductive liquid contained in the vessel, thereby improving the material after the solidification of the liquid more effectively.

(9) In case of (8), when the dc magnetic field generating electromagnetic coil is made up with a superconducting magnet, a still stronger generation of the compression waves in the conductive liquid contained in the vessel is effected, and an effective material improvement after the solidification of the liquid is accomplished more efficiently.

## Claims

1. An apparatus for generating compression waves in a conductive liquid(1), comprising a vessel (2) containing a conductive liquid (1) and an ac electromagnetic force applying means that generates the compression waves in the conductive liquid contained in the vessel, wherein an ac frequency f of the ac electromagnetic force applying means is set within a range given by the following[expression 1]:

   [expression 1]

   $$\frac{2}{L^2 \pi \mu \sigma} \leqq f \leqq \frac{c^2 \mu \sigma}{2\pi}$$

   here

   f: frequency (a major frequency when a waveform of anelectromagnetic force is developed by the Fourier transform, in case of the waveform being a non-sine wave)
   L: characteristic length of the system (for example, a depth, a radius of the vessel containing the conductive liquid)
   $\mu$ : permeability of the conductive liquid
   $\sigma$ : electric conductivity of the conductive liquid
   c: propagation velocity of the compression waves in the conductive liquid,

   charactarized in that
   a dc magnetic field generating electromagnetic coil (6) is provided around the circumference of the vessel (2), wherein the dc magnetic field generating electromagnetic coil is a superconducting magnet (6,6a).

2. An apparatus for generating compression waves in a conductive liquid, as claimed in claim 1, charactarized in that the ac electromagnetic force applying means is an ac magnetic field generating electromagnetic coil (3), which is provided around a circumference of the vessel (2).

3. An apparatus for generating compression waves in a conductive liquid, as claimed in claim 2, charactarized in that the vessel (2) and the ac magnetic field generating electromagnetic coil (3) are inserted in a bore of the superconducting magnet (6,6a).

4. An apparatus for generating compression waves in a conductive liquid, as claimed in claim 1, charactarized in that the ac electromagnetic force applying means comprises a pair of electrodes (7) that are installed at positions on a circumferential wall of the vessel (2) facing to each other so as to energize the conductive liquid, and an ac power supply connected to the electrodes.

5. An apparatus for generating compression waves in a conductive liquid, as claimed in claim 4, charactarized in that the vessel (2) with a pair of the electrodes is inserted in a bore of the superconducting magnet (6,6a).

6. An apparatus for generating compression waves in a conductive liquid, as claimed in claim 1, charactarized in that the vessel (2) is formed of ceramics and provided with a metal reinforcing material (8) on the circumference thereof, and an ac magnetic field generating electromagnetic coil (3) as the ac electromagnetic force applying means is provided overlying the vessel.

## Patentansprüche

1. Vorrichtung zur Erzeugung von Druckwellen in einer leitfähigen Flüssigkeit (1) mit einem eine leitfähige Flüssigkeit (1) enthaltenden Behälter (2) und einer Einrichtung zum Auferlegen einer AC-elektro-

magnetischen Kraft, die die Druckwellen in der in dem Behälter enthaltenden leitfähigen Flüssigkeit erzeugt, wobei eine AC-Frequenz f der Einrichtung zum Auferlegen einer AC-elektromagnetischen Kraft auf einen Wert innerhalb des durch den folgenden Ausdruck [Ausdruck 1] vorgegebenen Bereichs gesetzt ist:

[Ausdruck 1]

$$\frac{2}{L^2 \pi \mu \sigma} \leqq f \leqq \frac{c^2 \mu \sigma}{2\pi}$$

mit

- f: Frequenz (eine Hauptfrequenz, wenn eine Wellenform einer elektromagnetischen Kraft im Falle, dass die Wellenform keine Sinuswelle ist, durch die Fouriertransformation entwickelt worden ist),
- L: charakteristische Länge des Systems (z.B. eine Tiefe oder ein Radius des die leitfähige Flüssigkeit enthaltenden Behälters),
- μ: Permeabilität der leitfähigen Flüssigkeit,
- σ : elektrische Leitfähigkeit der leitfähigen Flüssigkeit,
- c: Fortschreitungsgeschwindigkeit der Druckwellen in der leitfähigen Flüssigkeit,

**dadurch gekennzeichnet, dass** eine ein magnetisches Gleichfeld oder DC-magnetisches Feld erzeugende elektromagnetische Spule (6) um den Umfang des Behälters (2) vorgesehen ist, wobei die das magnetische Gleichfeld oder DC-magnetische Feld erzeugende elektromagnetische Spule ein supraleitender Magnet (6, 6a) ist.

2. Vorrichtung zum Erzeugen von Druckwellen in einer leitfähigen Flüssigkeit nach Anspruch 1,
**dadurch gekennzeichnet,**
**dass** die Einrichtung zum Auferlegen einer AC-elektromagnetischen Kraft eine ein Wechselmagnetfeld oder AC-Magnetfeld erzeugende elektromagnetische Spule (3) ist, die um einen Umfang des Behälters (2) vorgesehen ist.

3. Vorrichtung zum Erzeugen von Druckwellen in einer leitfähigen Flüssigkeit, nach Anspruch 2,
**dadurch gekennzeichnet,**
**dass** der Behälter und die das Wechselmagnetfeld oder AC-Magnetfeld erzeugende elektromagnetische Spule (3) in einer Bohrung des supraleitenden Magnets (6, 6a) eingesetzt sind.

4. Vorrichtung zum Erzeugen von Druckwellen in einer leitfähigen Flüssigkeit, nach Anspruch 1,
**dadurch gekennzeichnet,**
**dass** die die AC-elektromagnetische Kraft aufbringende Einrichtung ein Paar von Elektroden (7), die an Stellen an einer Umfangswand des Behälters (2) installiert sind, die zueinander gewandt sind, um so die leitfähige Flüssigkeit mit Energie zu versorgen, und eine Wechselstrom- oder Wechselspannungsversorgung, die mit den Elektroden verbunden ist, aufweist.

5. Vorrichtung zum Erzeugen von Druckwellen in einer leitfähigen Flüssigkeit, nach Anspruch 4,
**dadurch gekennzeichnet,**
**dass** der Behälter (2) mit dem Paar von Elektroden in einer Bohrung des supraleitenden Magnetes (6, 6a) eingesetzt ist.

6. Vorrichtung zum Erzeugen von Druckwellen in einer leitfähigen Flüssigkeit, nach Anspruch 1,
**dadurch gekennzeichnet,**
**dass** der Behälter (2) aus Keramik gebildet ist und an dem Umfang davon mit einem Metallverstärkungsmaterial (8) versehen ist, und eine ein Wechselmagnetfeld oder AC-Magnetfeld erzeugende elektromagnetische Spule (3) als die die AC-elektromagnetische Kraft aufbringende Einrichtung den Kessel überlagernd vorgesehen ist.

**Revendications**

1. Dispositif pour générer des ondes de compression dans un liquide électro-conducteur (1) qui comprend un bac (2) contenant un liquide électro-conducteur et un moyen pour appliquer une force électromagnétique alternative qui génère les ondes de compression dans le liquide électro-conducteur contenu dans le bac, dans lequel une fréquence alternative f du dispositif d'application de la force électromagnétique est réglée dans une gamme donnée par l'expression [1] suivante :

[expression 1]

$$\frac{2}{L^2 \pi \mu \sigma} \leqq f \leqq \frac{c^2 \mu \sigma}{2\pi}$$

Où :

f: fréquence (fréquence principale quand une forme d'onde de force électromagnétique est développée par la transformée de Fourier, dans le cas où la forme d'onde n'est pas sinusoïdale)
L : longueur caractéristique du système (par exemple, une profondeur, un rayon du bac contenant le liquide électroconducteurconducteur)
μ : perméabilité du liquide électro-conducteur
σ : conductivité électrique du liquide électro-

conducteur
c : vitesse de propagation des ondes de compression dans le liquide électro-conducteur,

**caractérisé en ce qu'**
une bobine électromagnétique (6) générant un champ magnétique continu est en outre montée de façon à entourer la circonférence du bac (2), la bobine électromagnétique générant un champ magnétique continu étant un aimant supraconducteur (6, 6a).

2. Dispositif pour générer des ondes de compression dans un liquide électro-conducteur selon la revendication 1,
**caractérisé en ce que**
le moyen pour appliquer une force électromagnétique est une bobine électromagnétique (3) générant un champ magnétique alternatif qui est montée sur la circonférence du bac (2).

3. Dispositif pour générer des ondes de compression dans un liquide électro-conducteur selon la revendication 2,
**caractérisé en ce que**
le bac (2) et la bobine électromagnétique (3) générant un champ magnétique alternatif sont insérés dans l'alésage de l'aimant supraconducteur (6, 6a).

4. Dispositif pour générer des ondes de compression dans un liquide électro-conducteur selon la revendication 1,
**caractérisé en ce que**
le moyen pour appliquer une force électromagnétique comprend deux électrodes (7) montées en des points de la paroi de circonférence du bac (2) en face l'un de l'autre, de façon à mettre sous tension le liquide électro-conducteur et une alimentation en courant alternatif est raccordée aux électrodes.

5. Dispositif pour générer des ondes de compression dans un liquide électro-conducteur selon la revendication 4,
**caractérisé en ce que**
le bac (2) et les deux électrodes sont insérés dans un alésage de l'aimant supraconducteur (6, 6a).

6. Dispositif pour générer des ondes de compression dans un liquide électro-conducteur selon la revendication 1,
**caractérisé en ce que**
le bac (2) est constitué de céramique et doté d'une matière métallique de renfort (8) sur sa circonférence et une bobine électromagnétique (3) générant un champ magnétique alternatif est disposée de façon à surplomber le bac, comme moyen pour appliquer une force électromagnétique.

FIG. 1

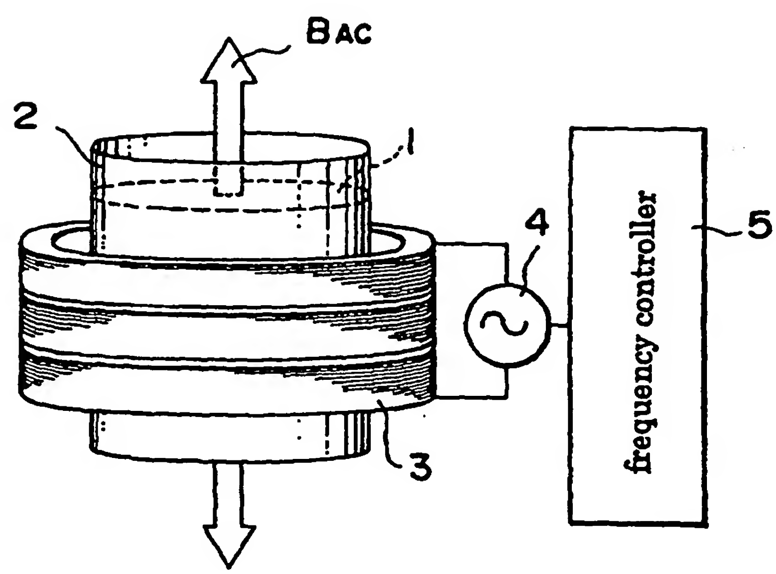


FIG. 2

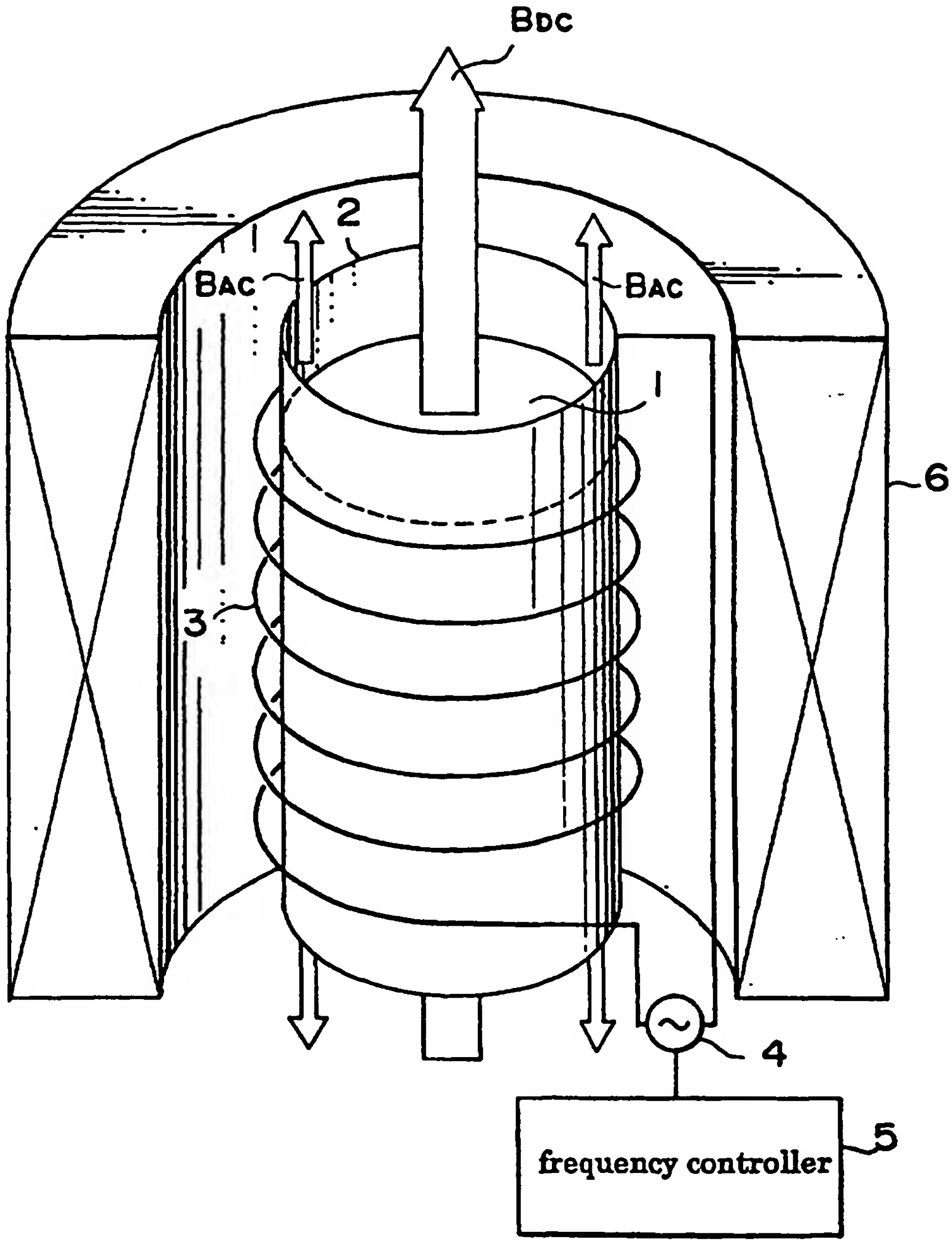


FIG. 3

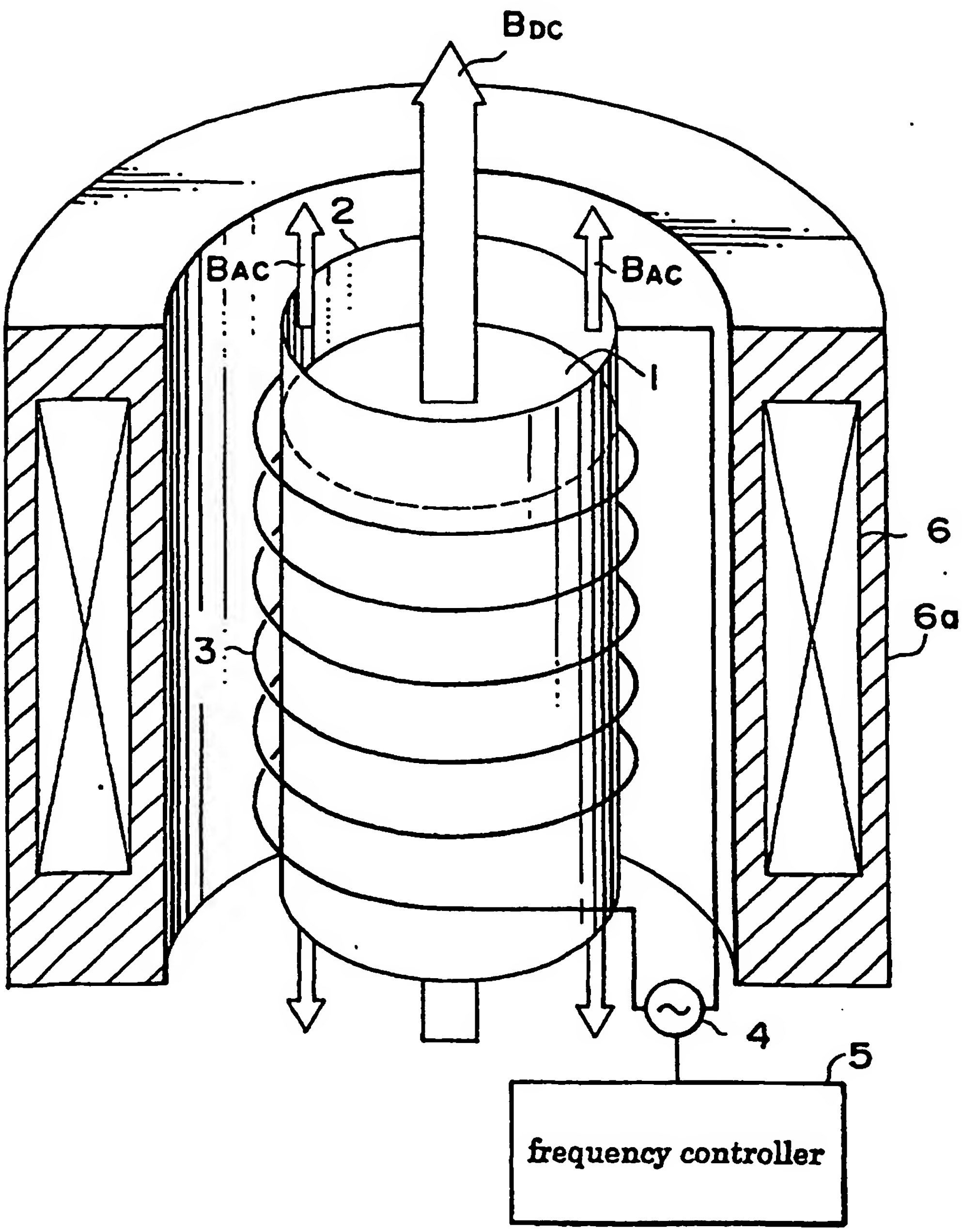


FIG. 4

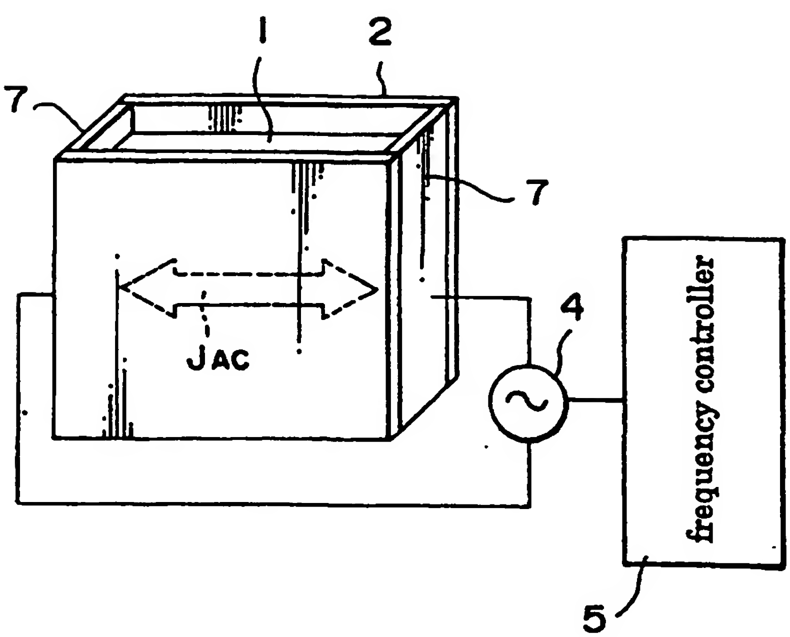


FIG. 5

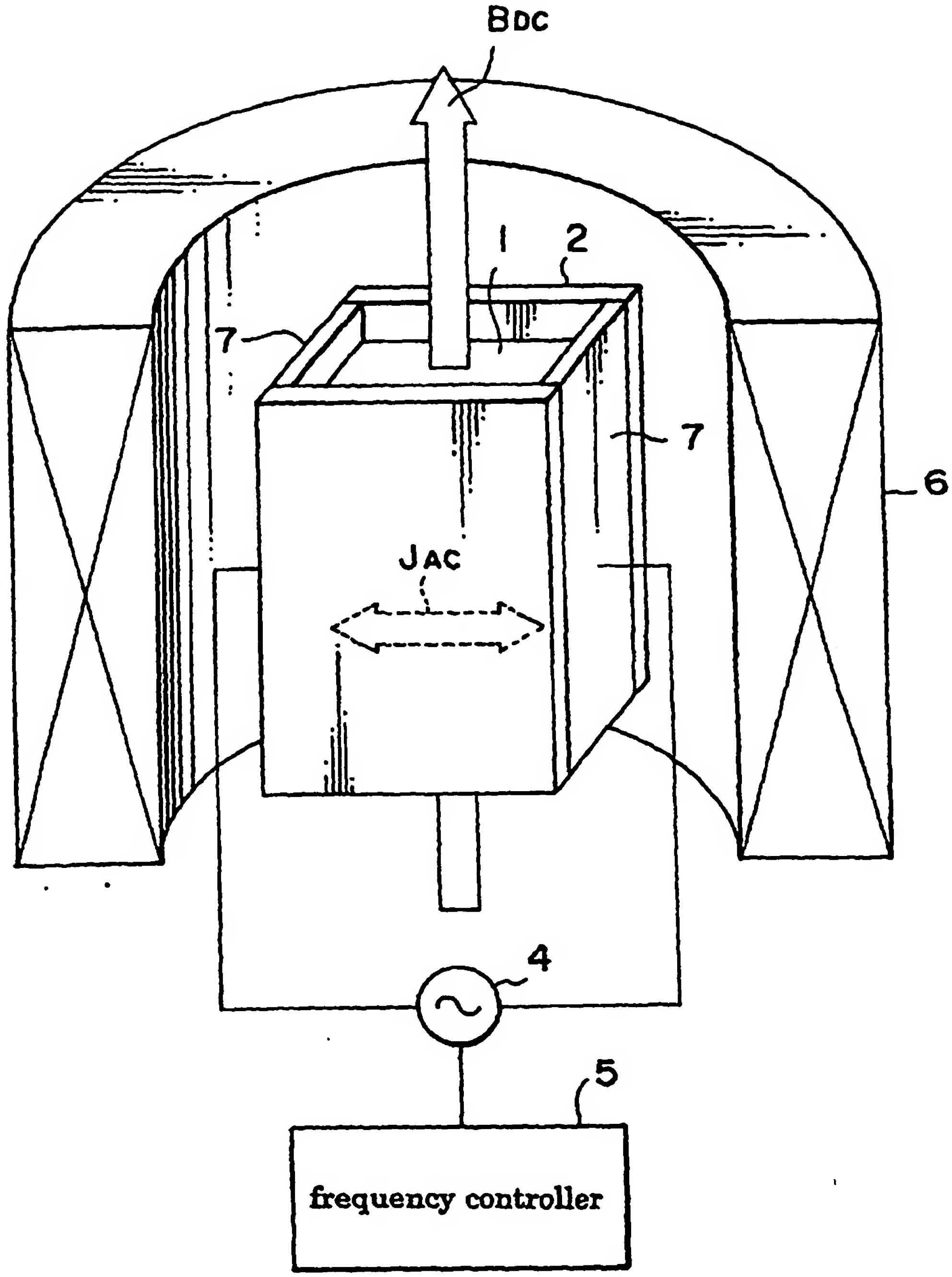


FIG. 6

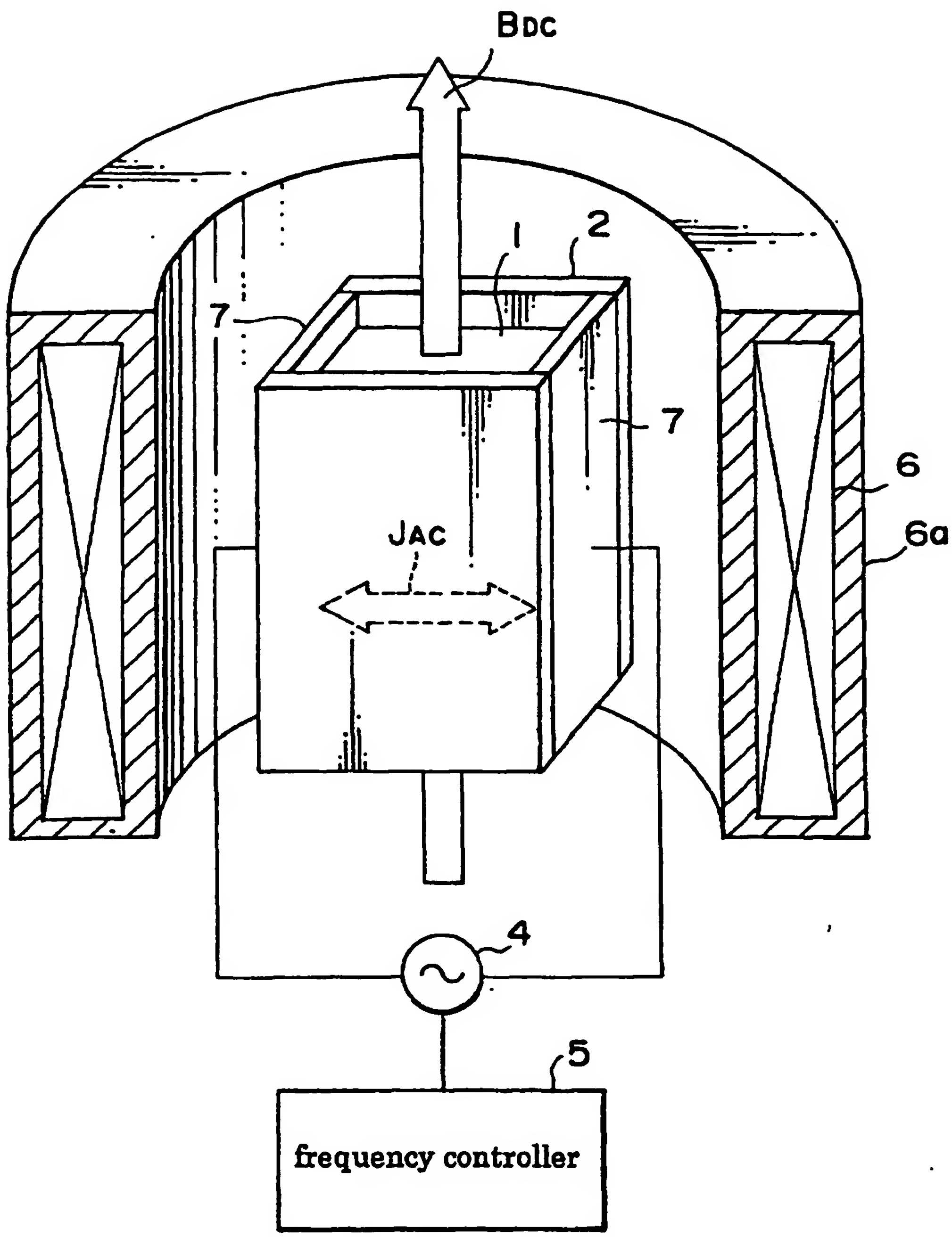
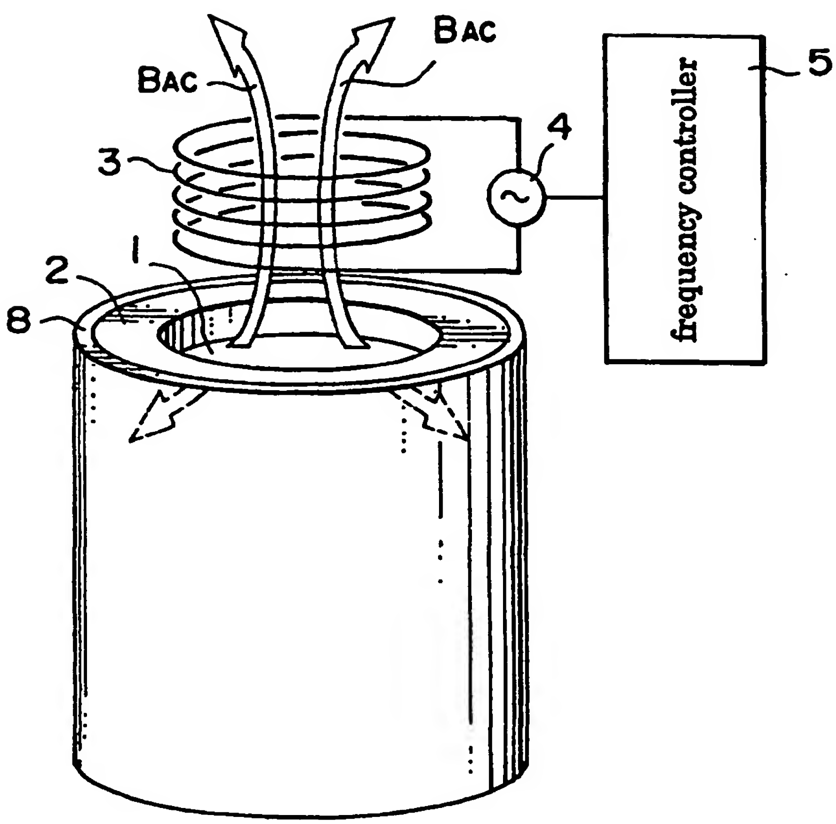


FIG. 7



# FIG. 8

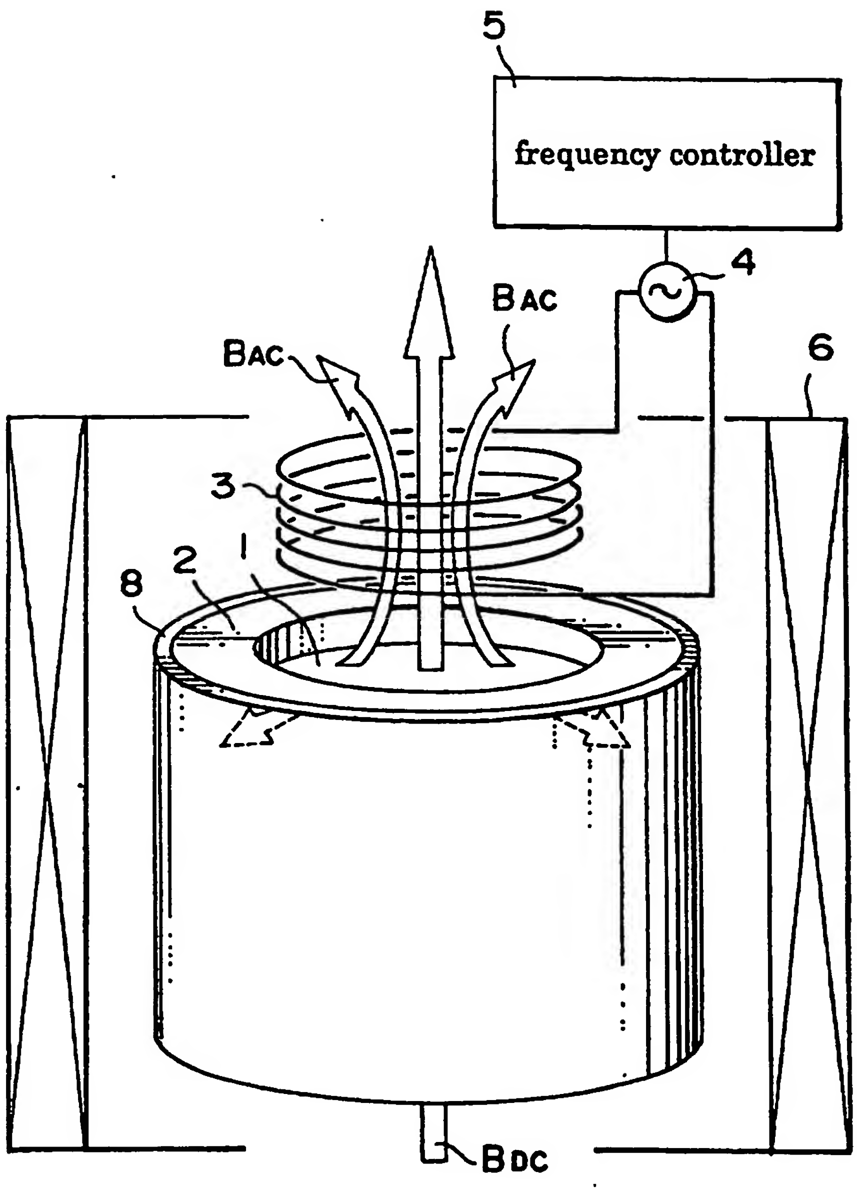
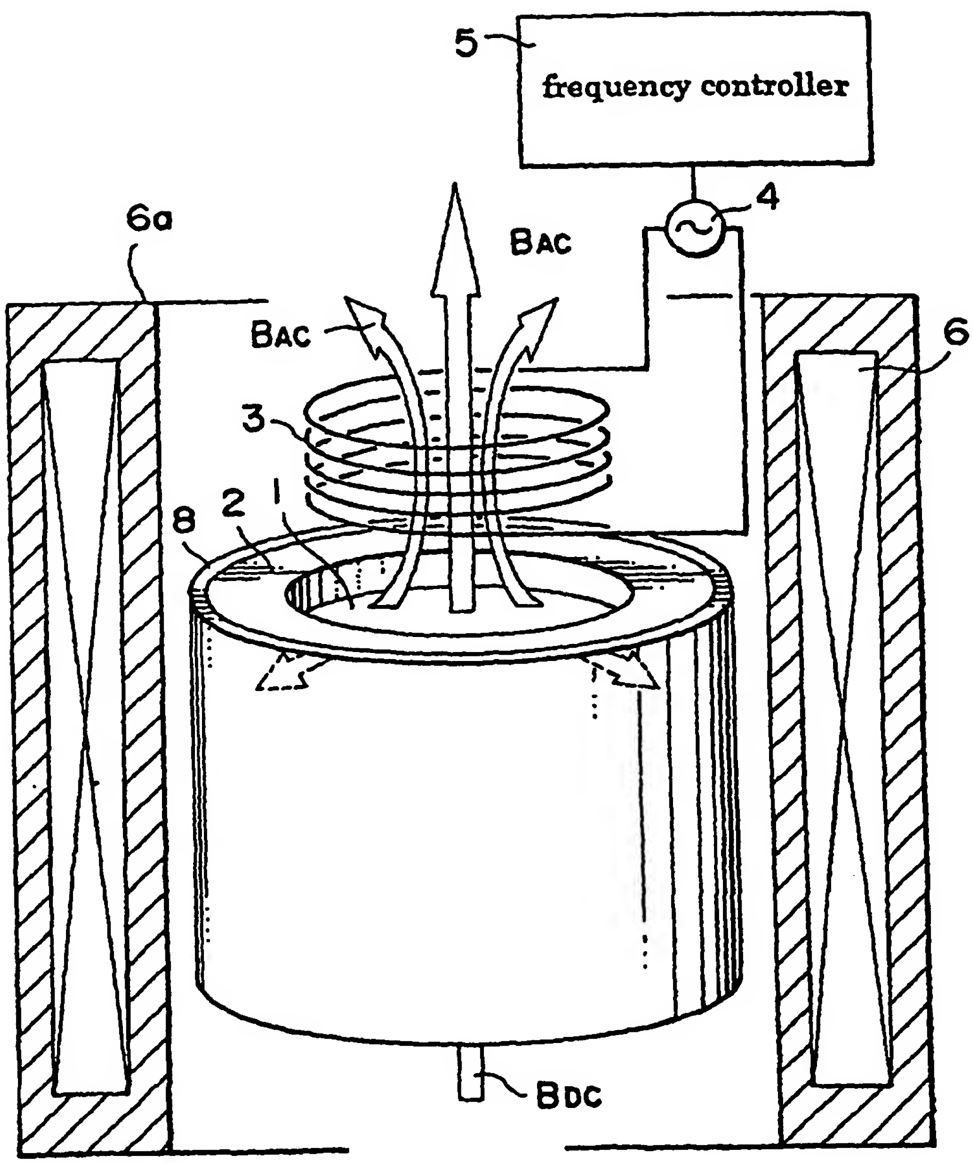


FIG. 9



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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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